



# How a wheat disease resistance gene atlas could lift up wheat breeding

Amber Hafeez  
PhD Student (Wulff/Brown Lab)  
John Innes Centre, UK  
06.05.2021

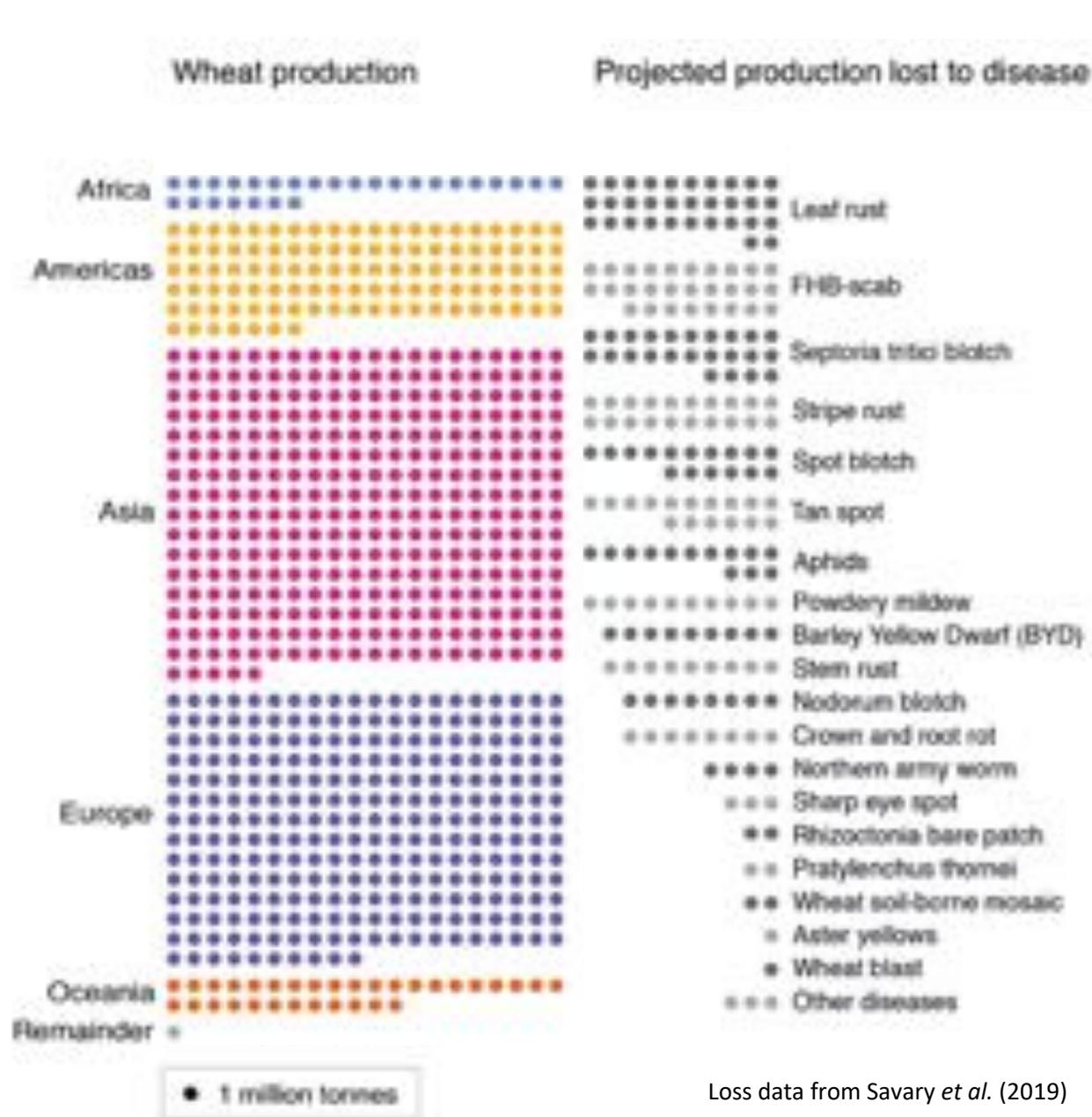
# Wheat in ancient Egypt

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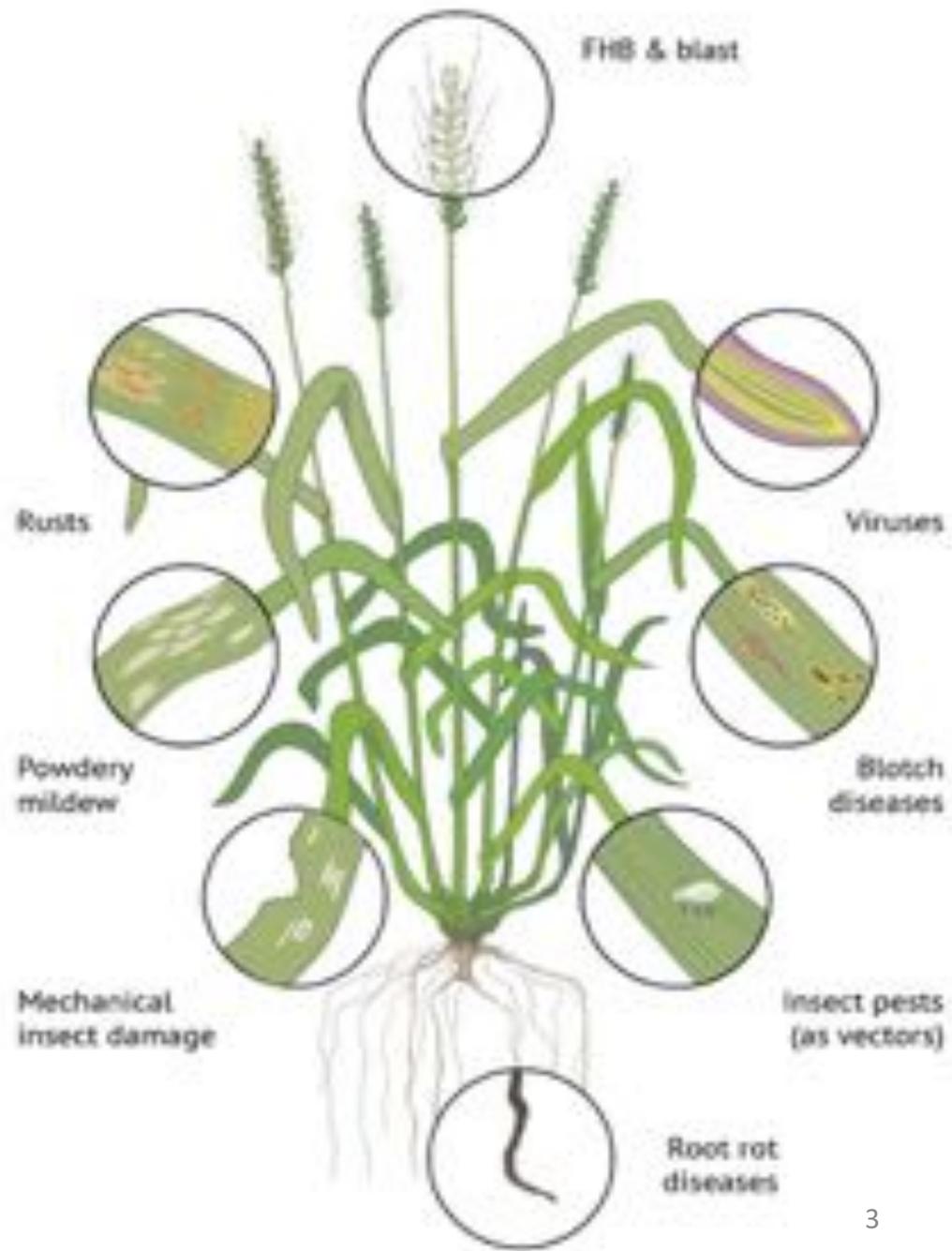


Middle Kingdom (2160-1785 B.C.)  
Egyptian Museum, Cairo

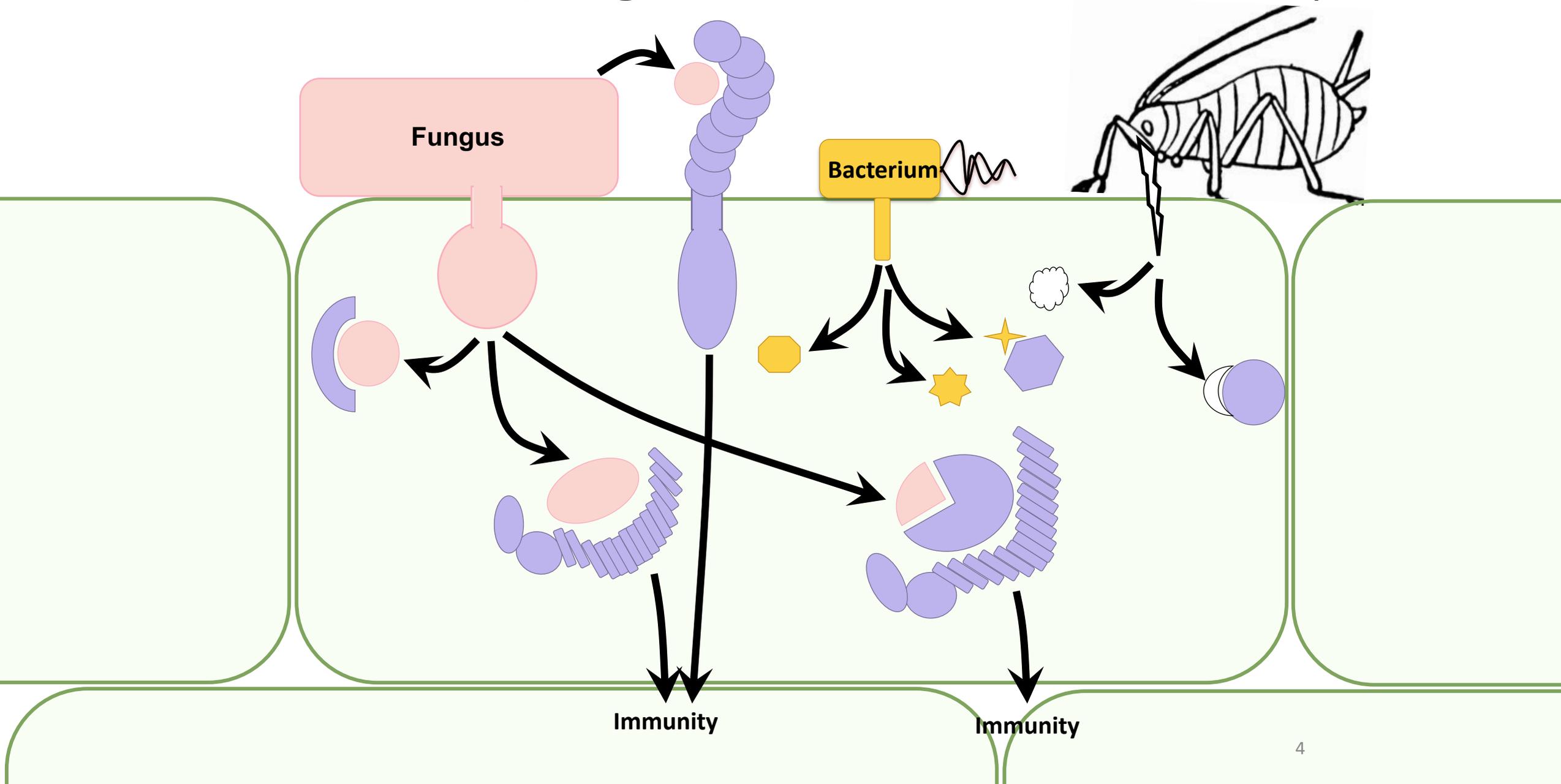




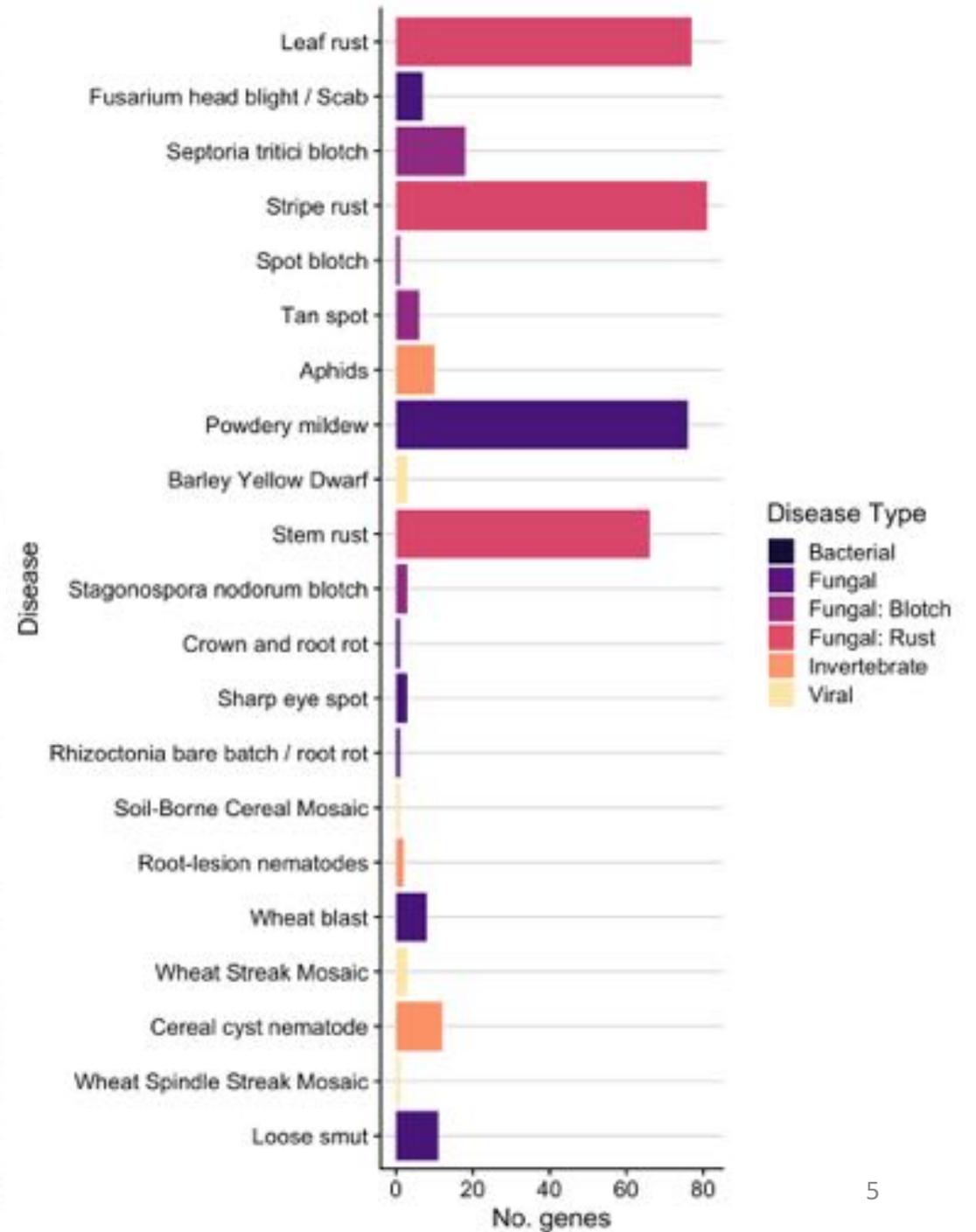
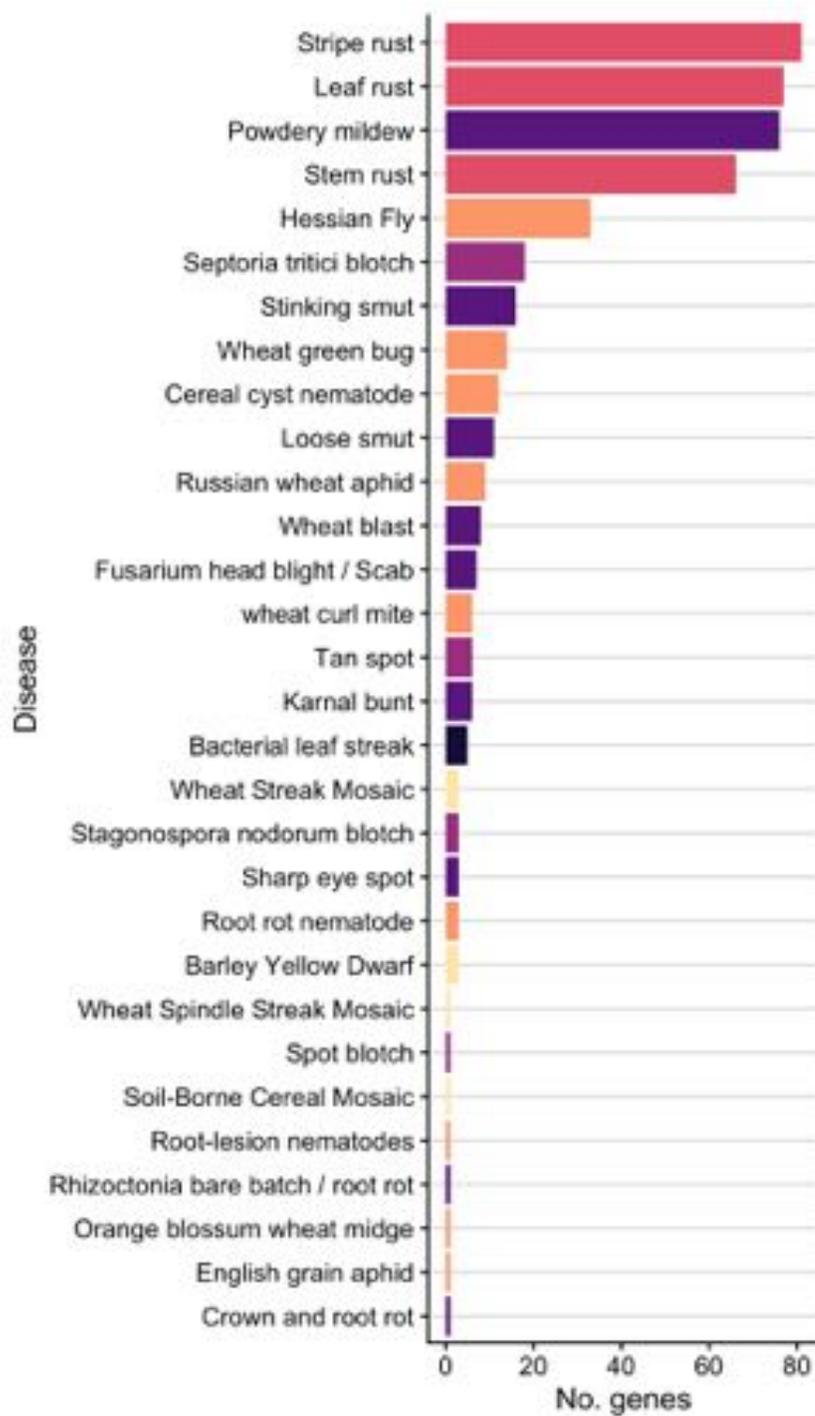
Loss data from Savary *et al.* (2019)



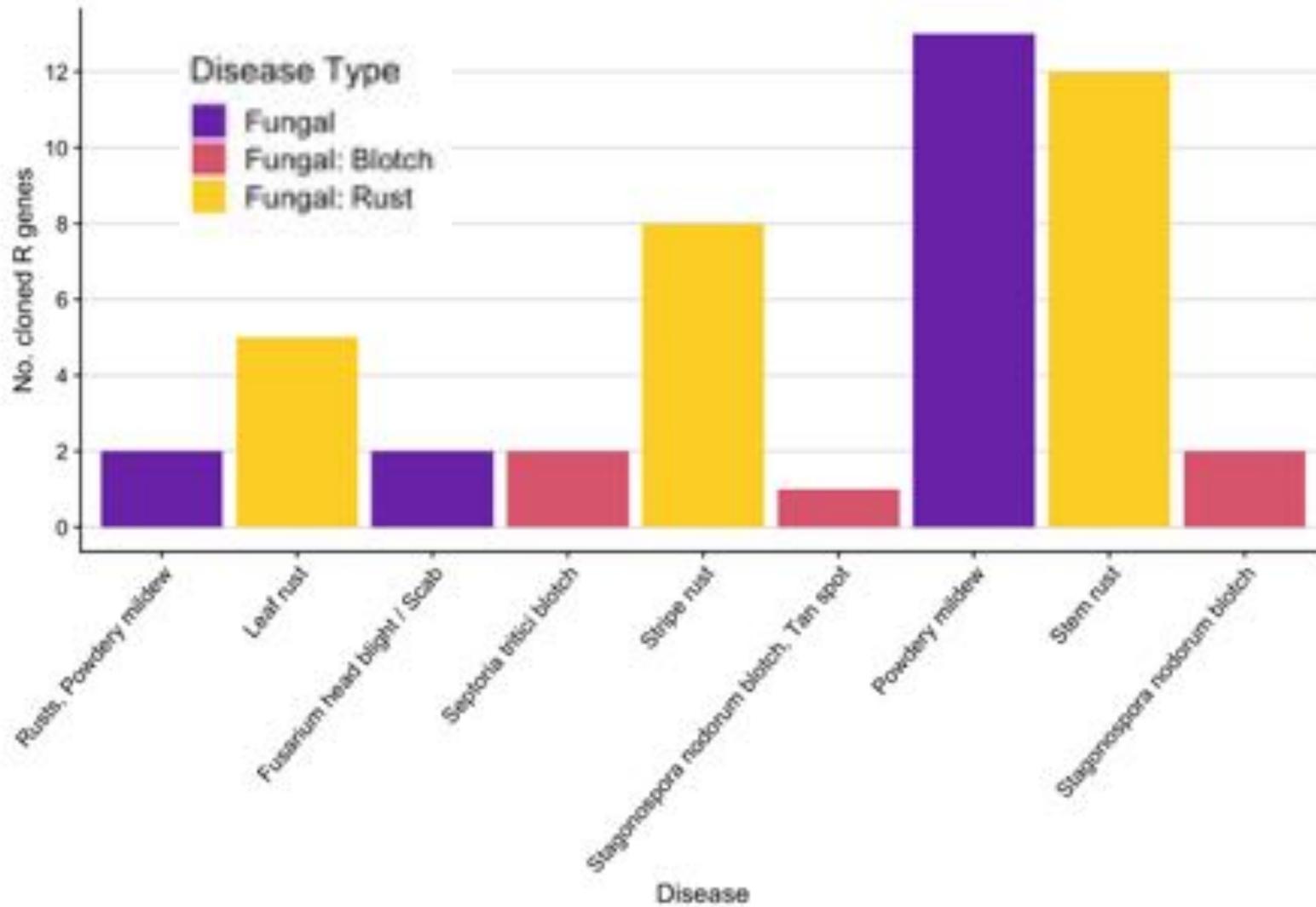
# Resistance (*R*) gene-mediated immunity



# Designated genes in wheat



# Cloned wheat *R* genes



# Cloned wheat *R* genes

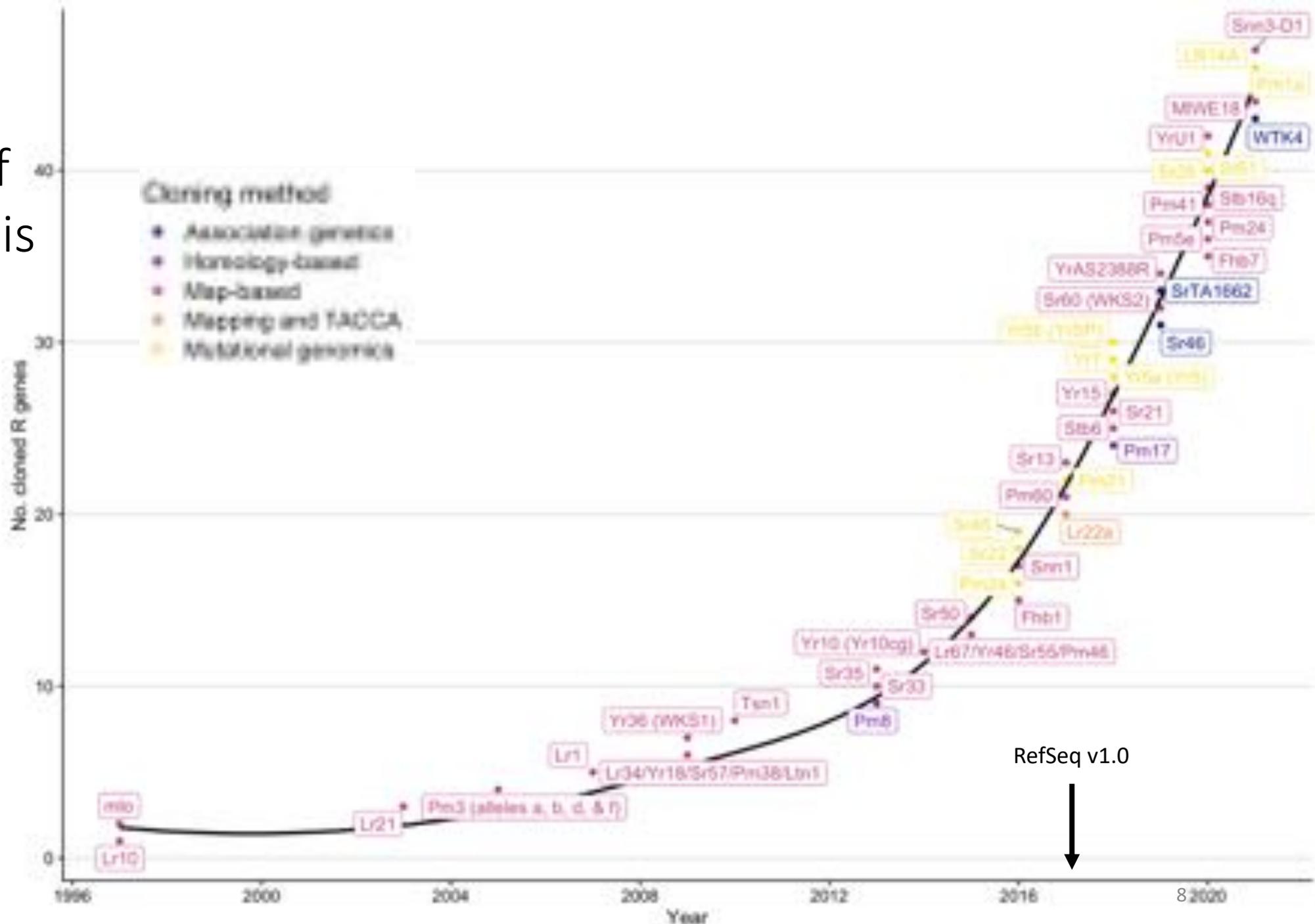
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A word cloud of cloned wheat *R* genes. The most prominent terms are 'NLR' in large purple font, 'BED-NLR' in purple, and 'Tandem\_kinase' in large blue font. Other significant terms include 'Wall-associated\_receptor\_kinase' in blue, 'START\_Kinase' in red, and 'ANP-TM' in green. Smaller terms include 'Serine/threonine\_protein\_kinase-NLR', 'Cysteine-rich\_receptor-like\_kinase', 'ANP-NLR-WPKY', 'Protein\_kinase-MSP', 'Tandem\_kinase-pseudokinase', 'Abscisic\_acid\_transporter', 'Hexose\_transporter', 'Transmembrane\_protein', 'Pore-forming\_toxin-like\_gene', and 'Glutathione\_S-transferase'.

Serine/threonine\_protein\_kinase-NLR Cysteine-rich\_receptor-like\_kinase  
ANP-TM Wall-associated\_receptor\_kinase  
BED-NLR Tandem\_kinase  
NLR ANP-NLR-WPKY START\_Kinase  
Protein\_kinase-MSP Tandem\_kinase-pseudokinase  
Abscisic\_acid\_transporter Hexose\_transporter Transmembrane\_protein  
Pore-forming\_toxin-like\_gene  
Glutathione\_S-transferase

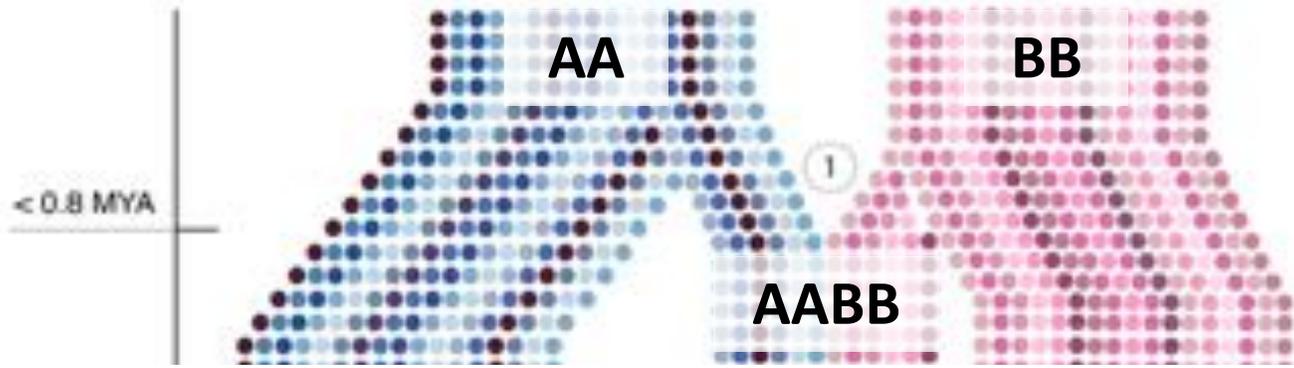
The number of cloned *R* genes is growing exponentially



Adapted from Keller et al. 2019

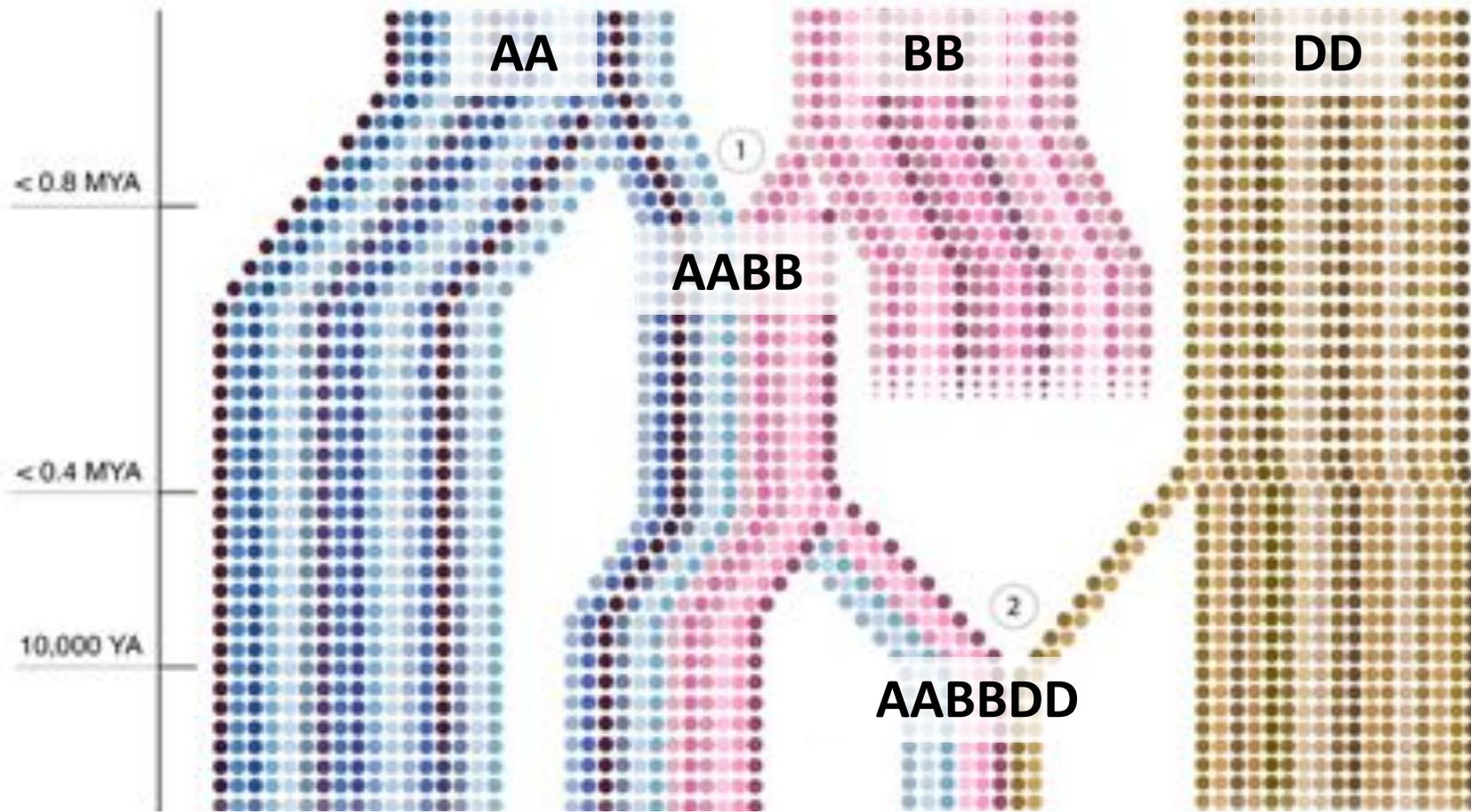
Where can we  
find these  $R$   
genes?

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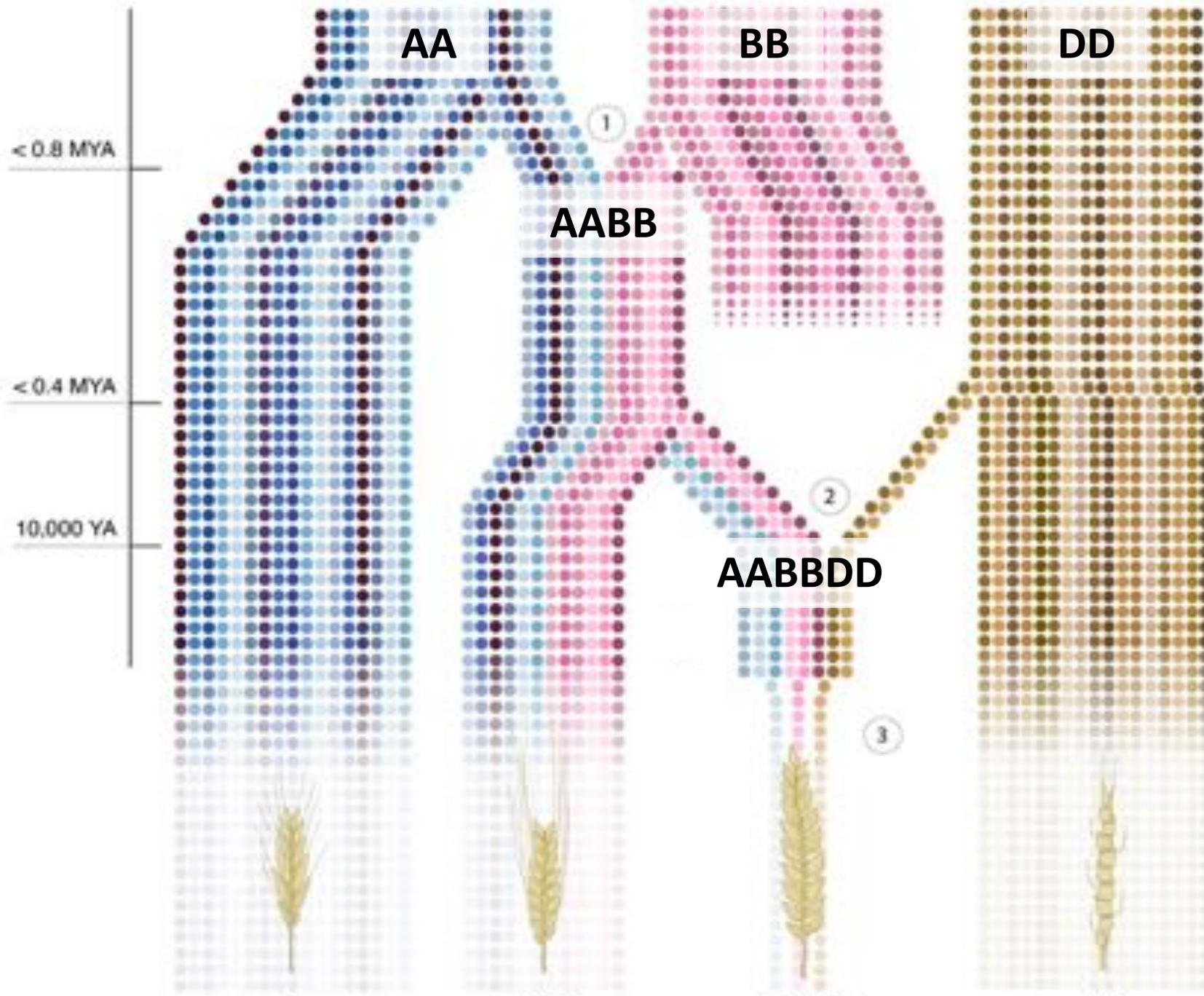
Where can we  
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genes?

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Where can we find these *R* genes?

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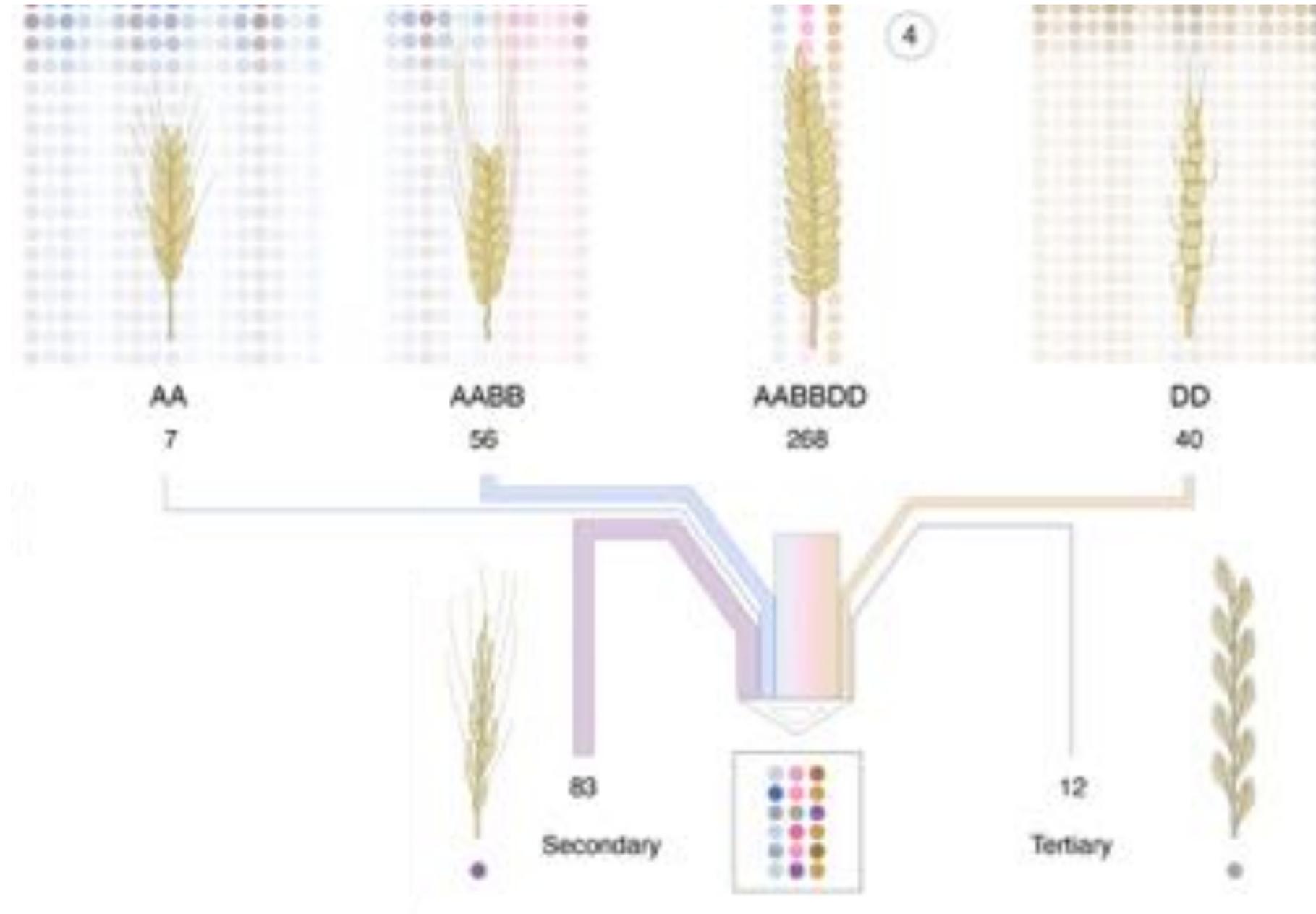


Where can we find these *R* genes?

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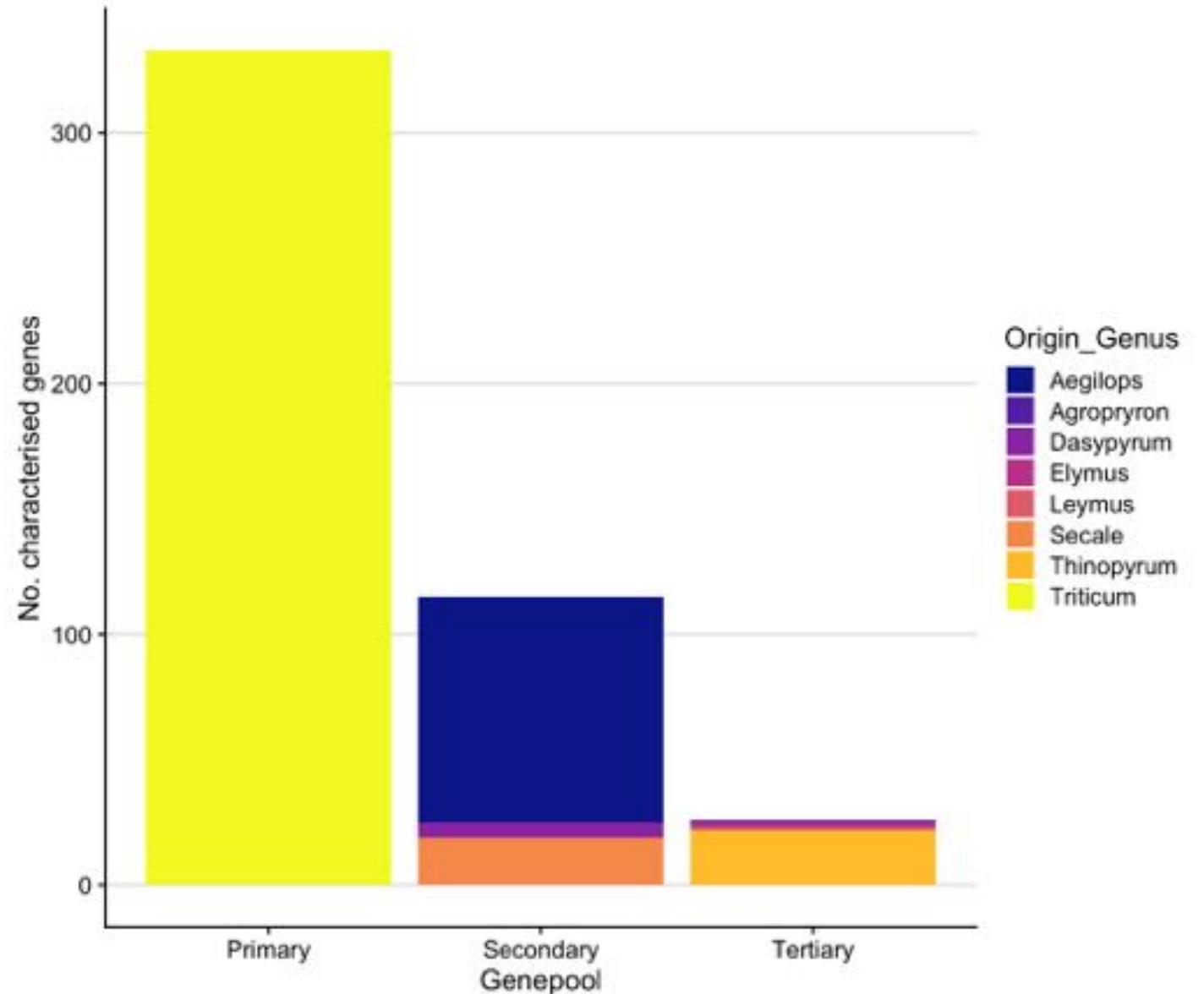
Where can we find these *R* genes?

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Most genes have been characterised from Triticum species

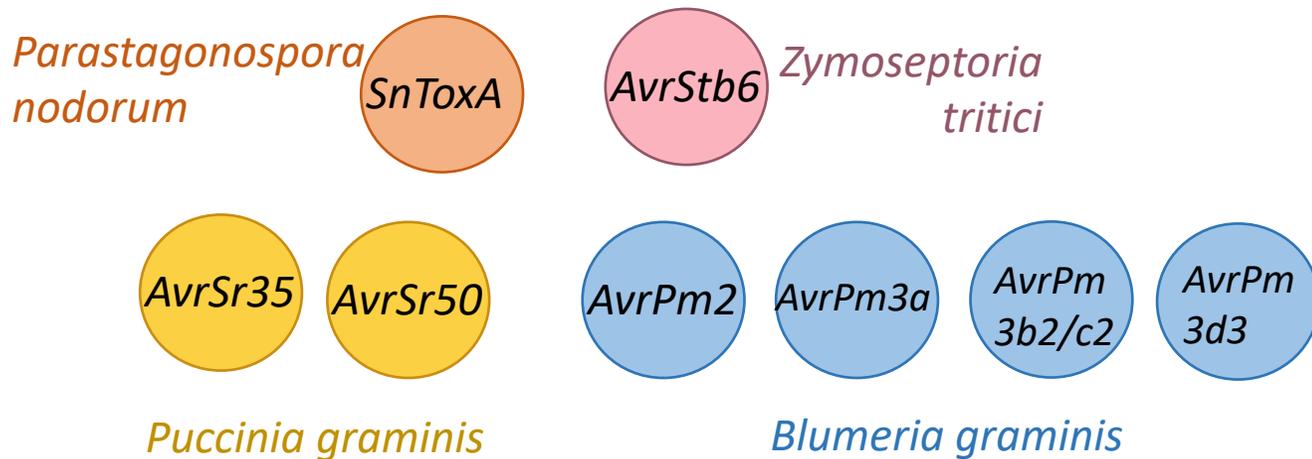
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# Effector cloning

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- Cloning effectors has been lagging behind
- Molecular diagnostics of virulence
- Testing the function of cloned *R* genes

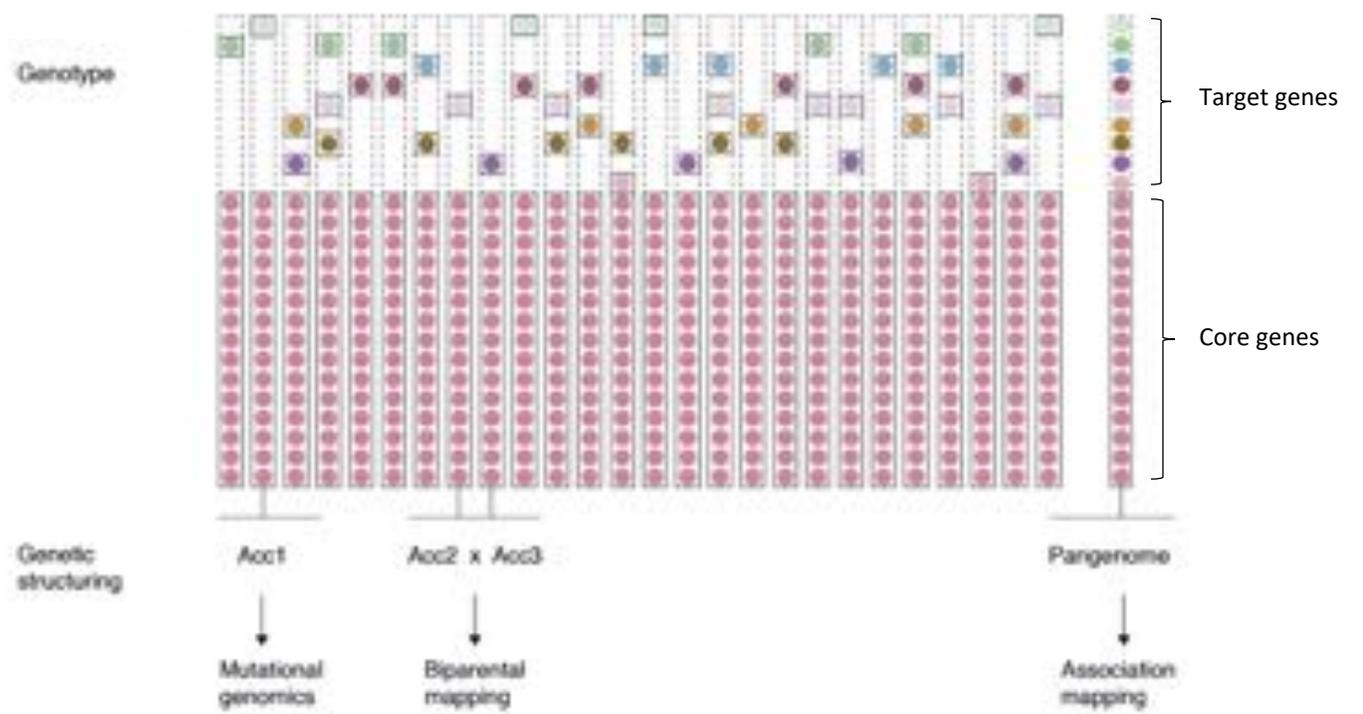




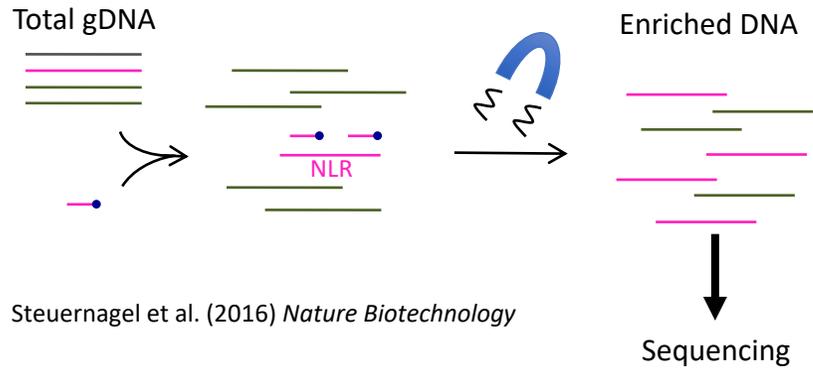
*Aegilops tauschii*  
XX XX XX XX XX XX XX



*Triticum aestivum*  
XX XX XX XX XX XX XX  
XX XX XX XX XX XX XX  
XX XX XX XX XX XX XX

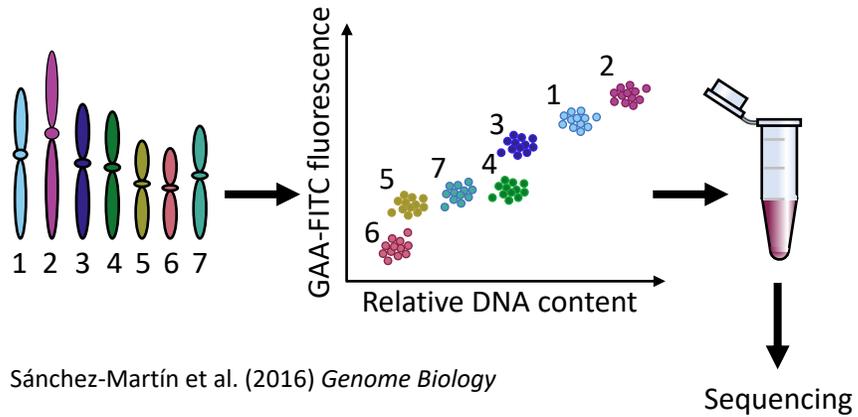


### R gene enrichment sequencing



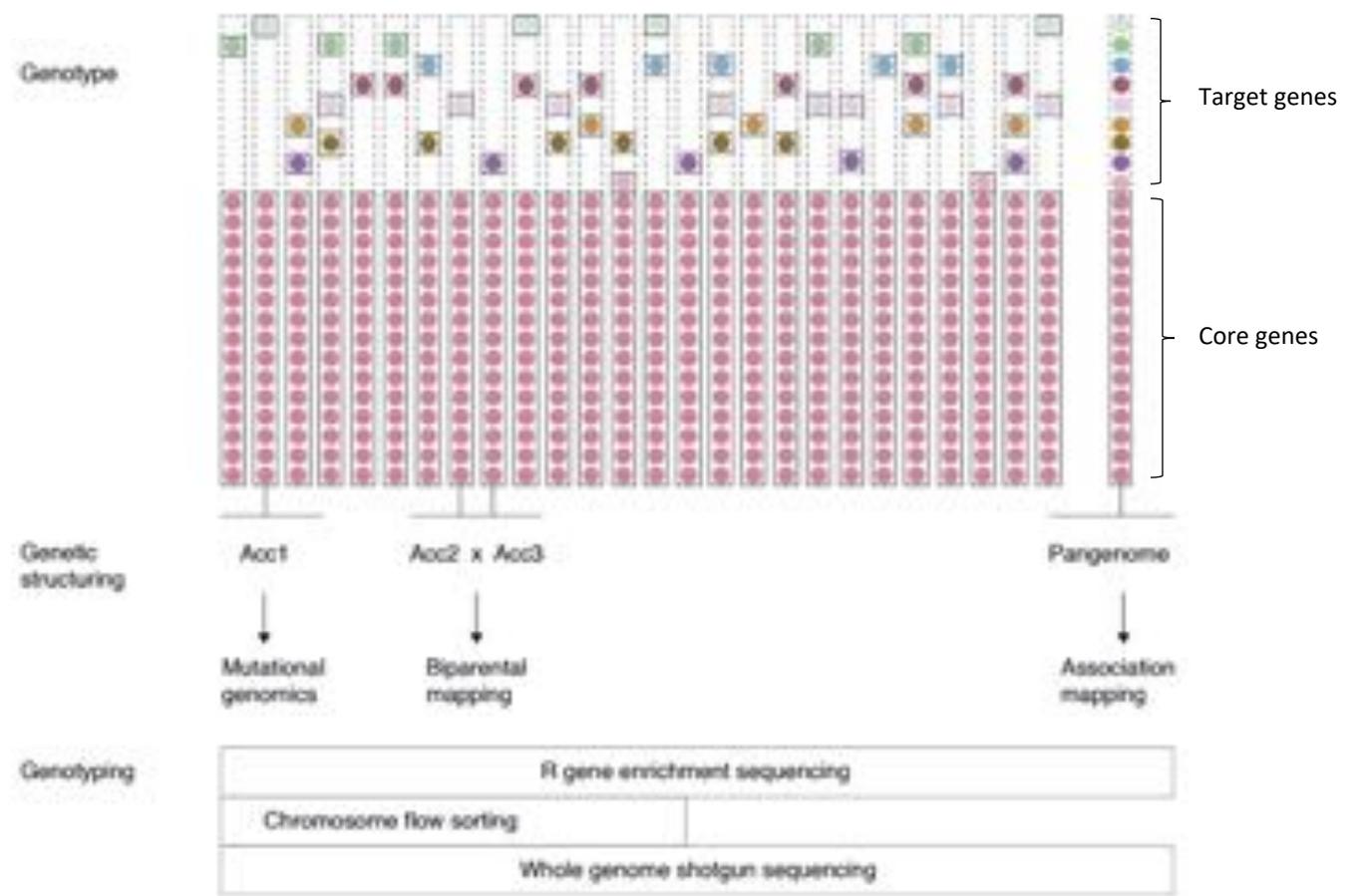
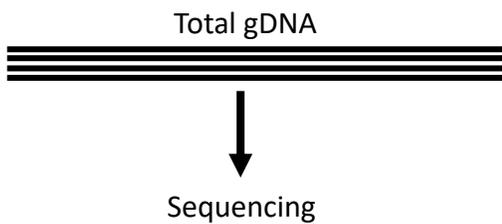
Steuernagel et al. (2016) *Nature Biotechnology*

### Chromosome flow sorting, amplification and sequencing

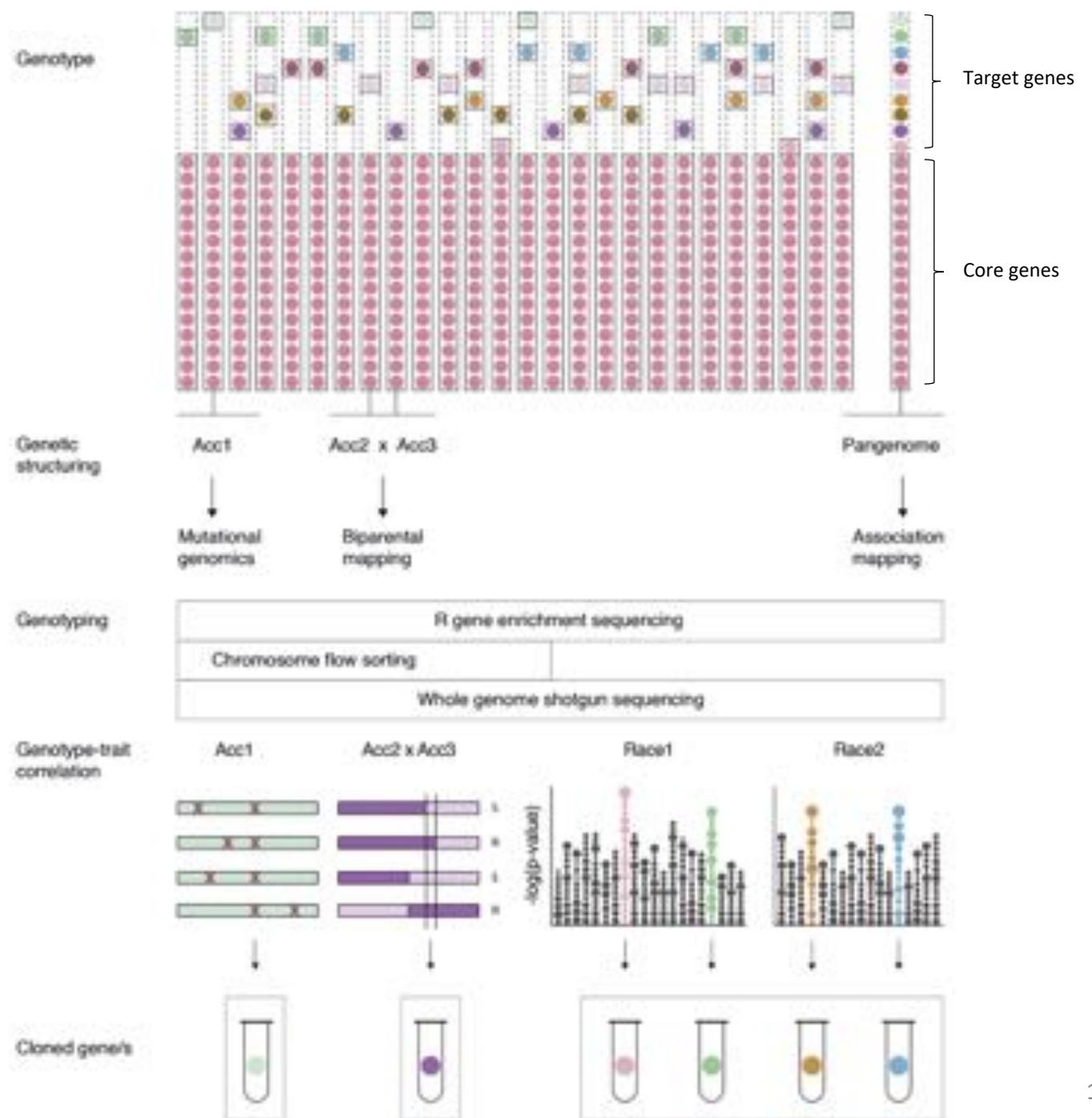


Sánchez-Martín et al. (2016) *Genome Biology*

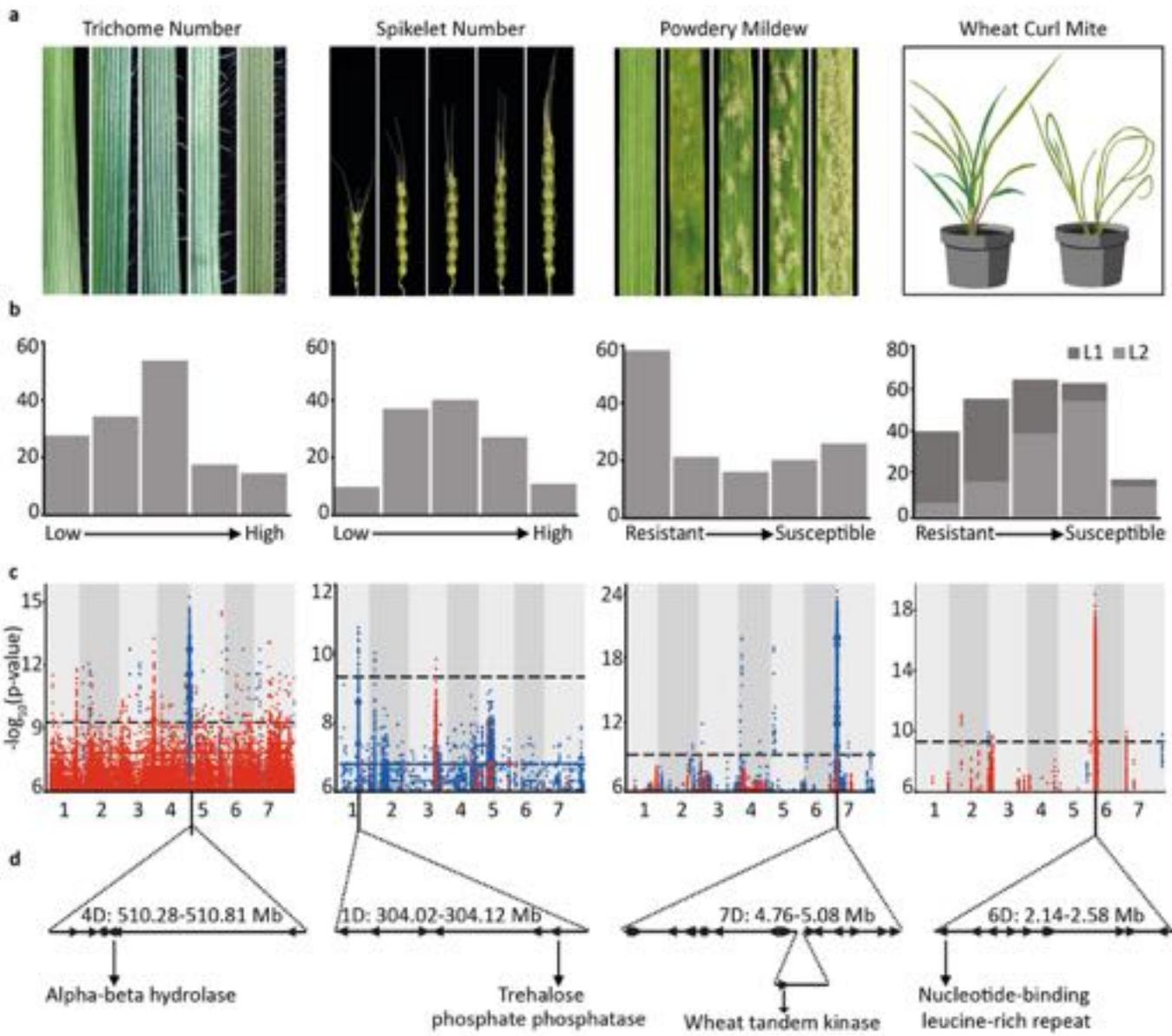
### Whole-genome shotgun sequencing



# Gene cloning methods



# Candidate gene discovery in *Aegilops tauschii* by GWAS



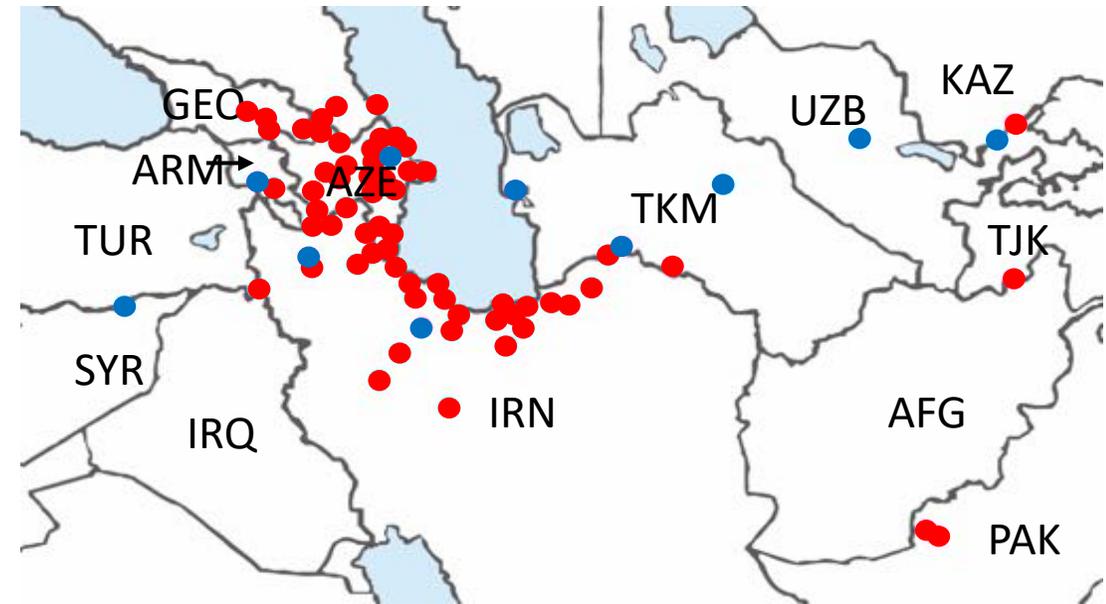
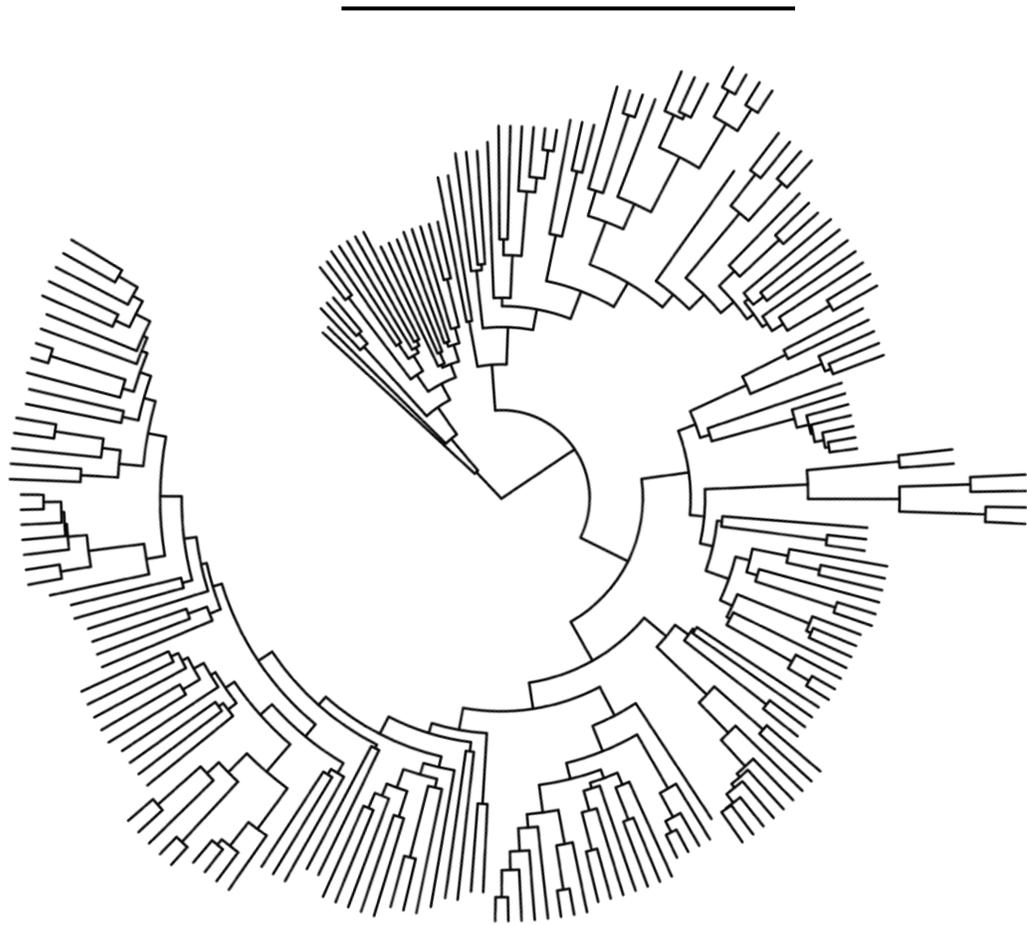
Open Wild Wheat Consortium  
Gaurav et al. (2021) *BioRxiv*

# Quality-checking diversity panels

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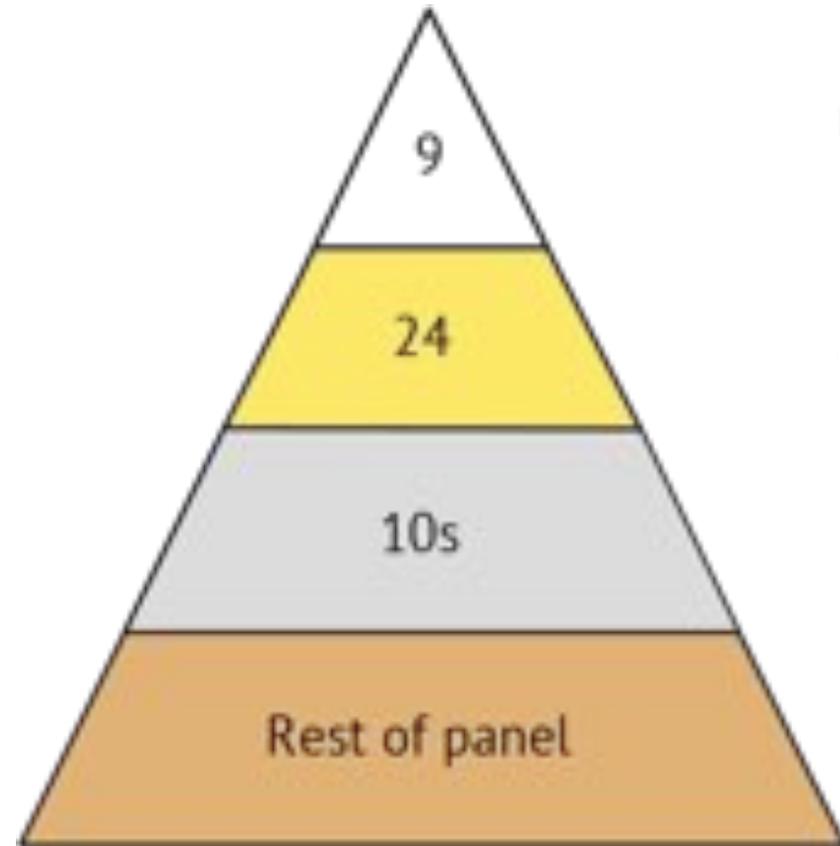
# Quality-checking diversity panels



Arora, Steuernagel et al. (2019) *Nature Biotechnology*

# A tiered sequencing approach

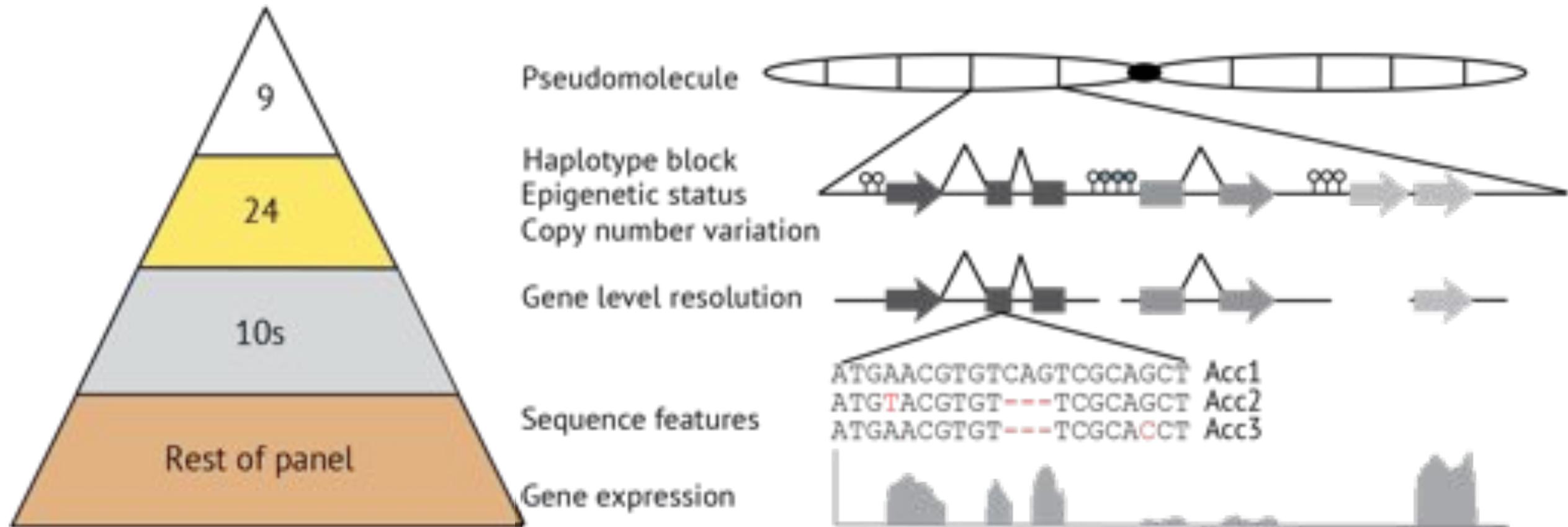
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Pseudomolecule



# Sequencing - bells and whistles



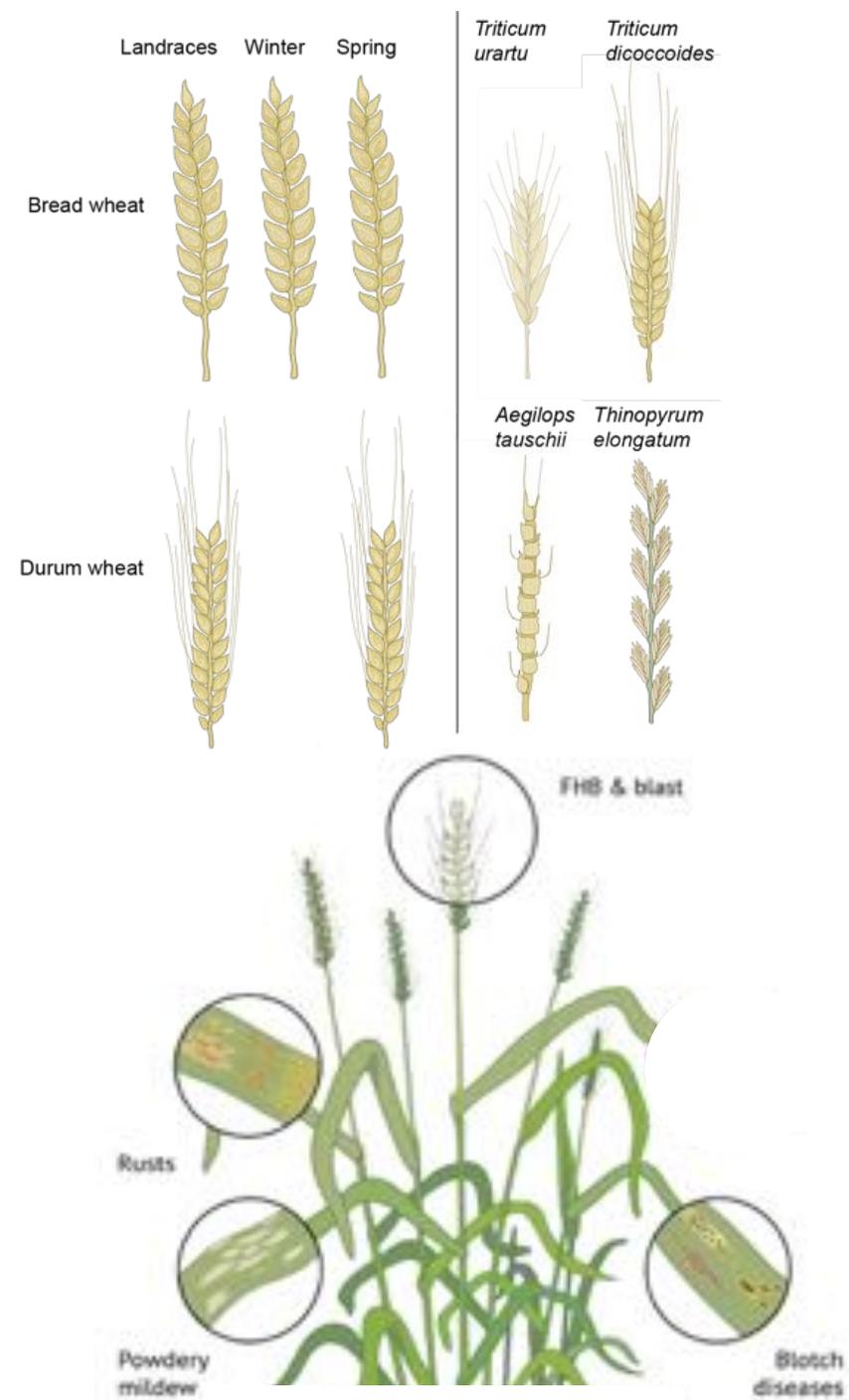
# The Atlas budget

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- 10 host and 9 pathogen diversity panels
  - \$7.6 million for sequencing
- ~\$50 million over 5 years for staff/consumables
  - 375 full-time employment years
  - \$2.9 million/year from each G20



Mark Luterbacher



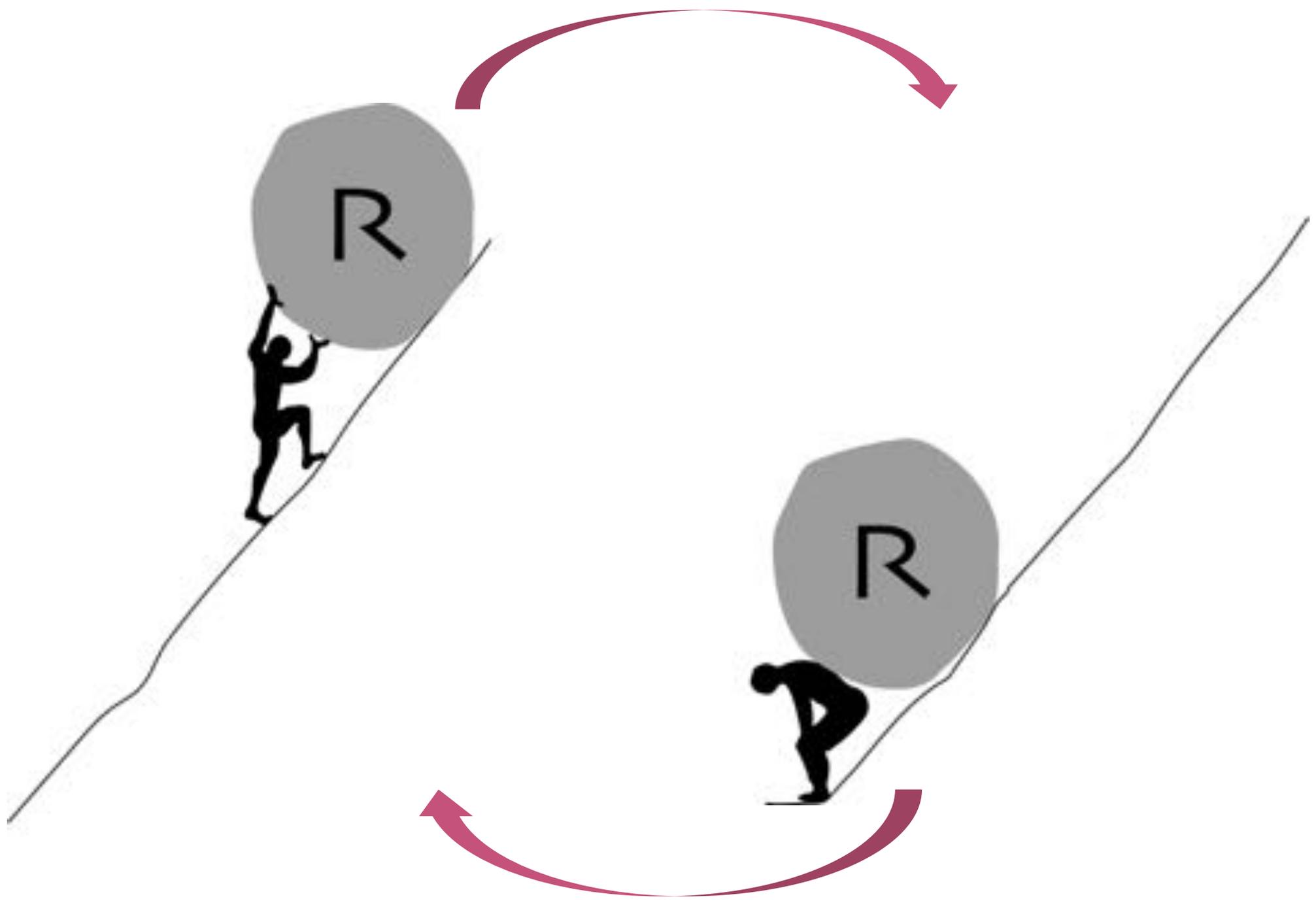
# Return on investment

\$1



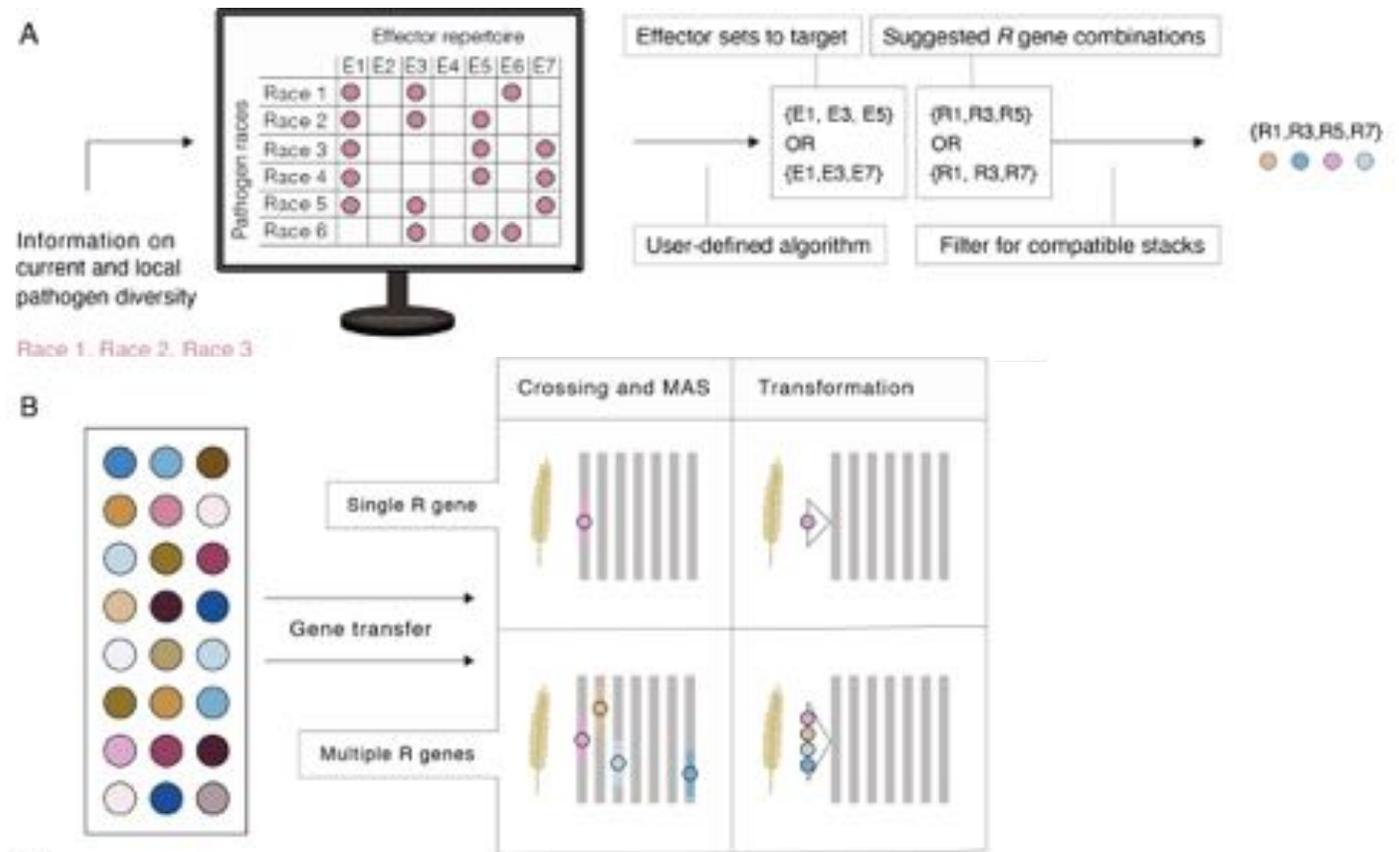
Wheat *R* gene atlas  
reducing pathogen  
losses by 1%



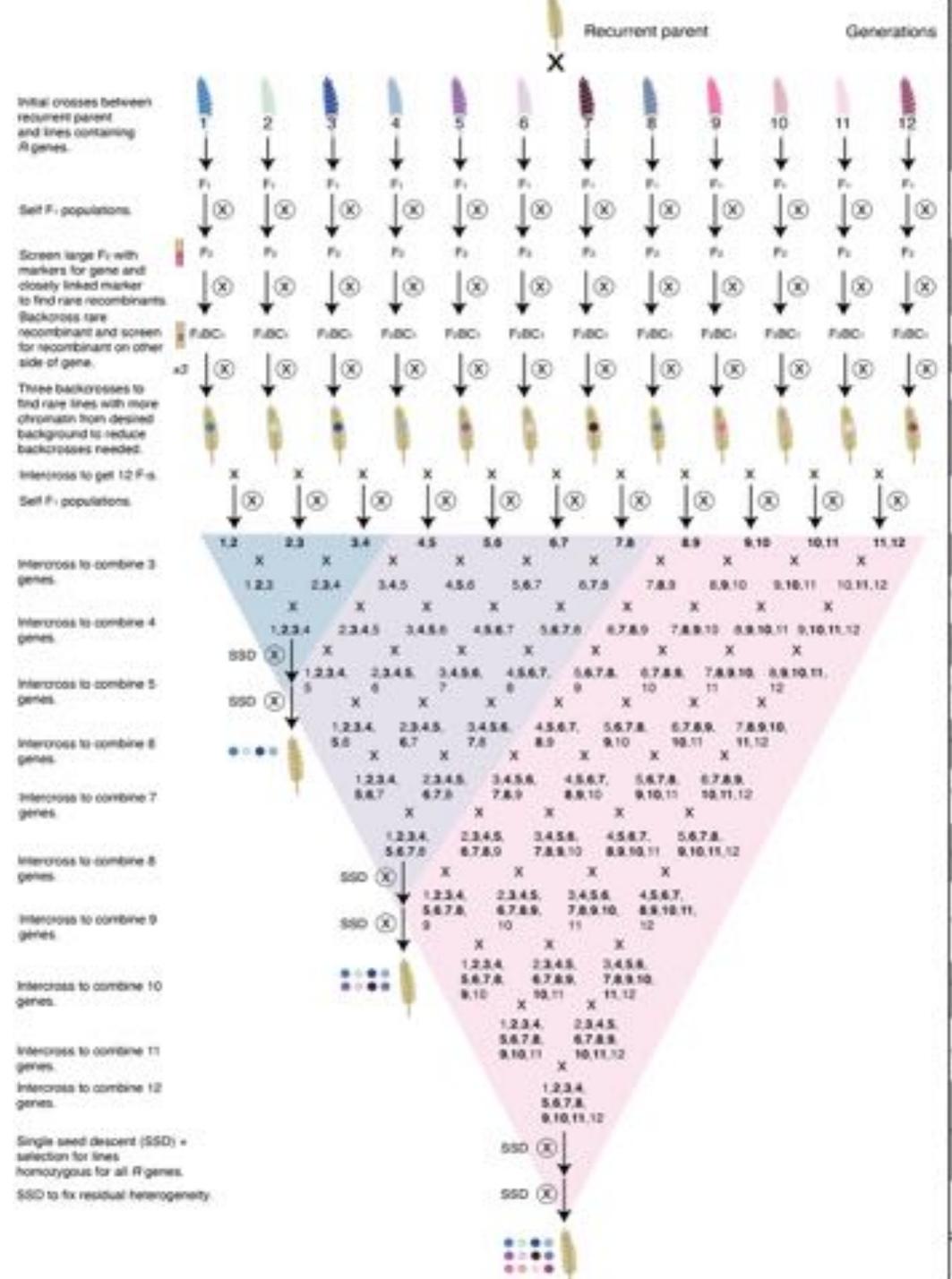


# R gene deployment

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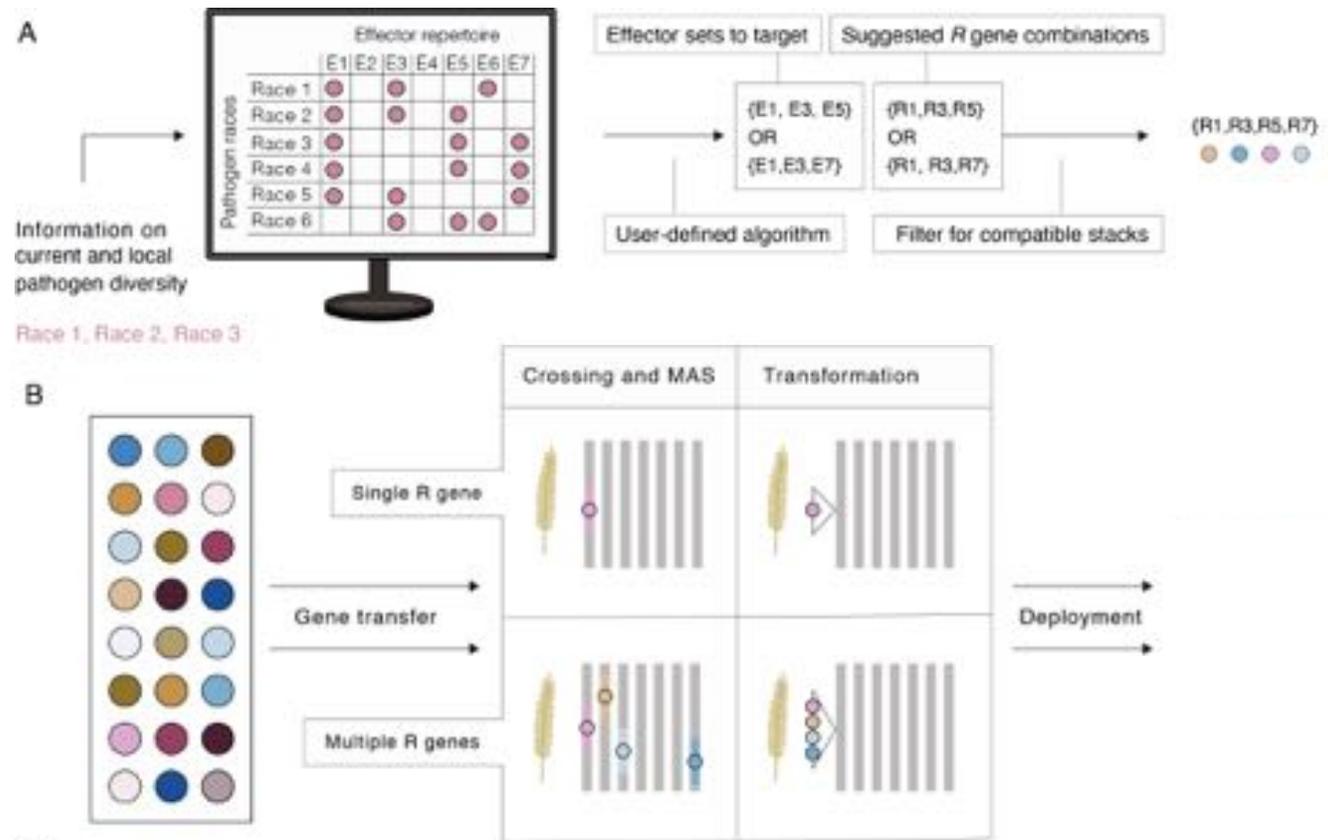


# R gene deployment

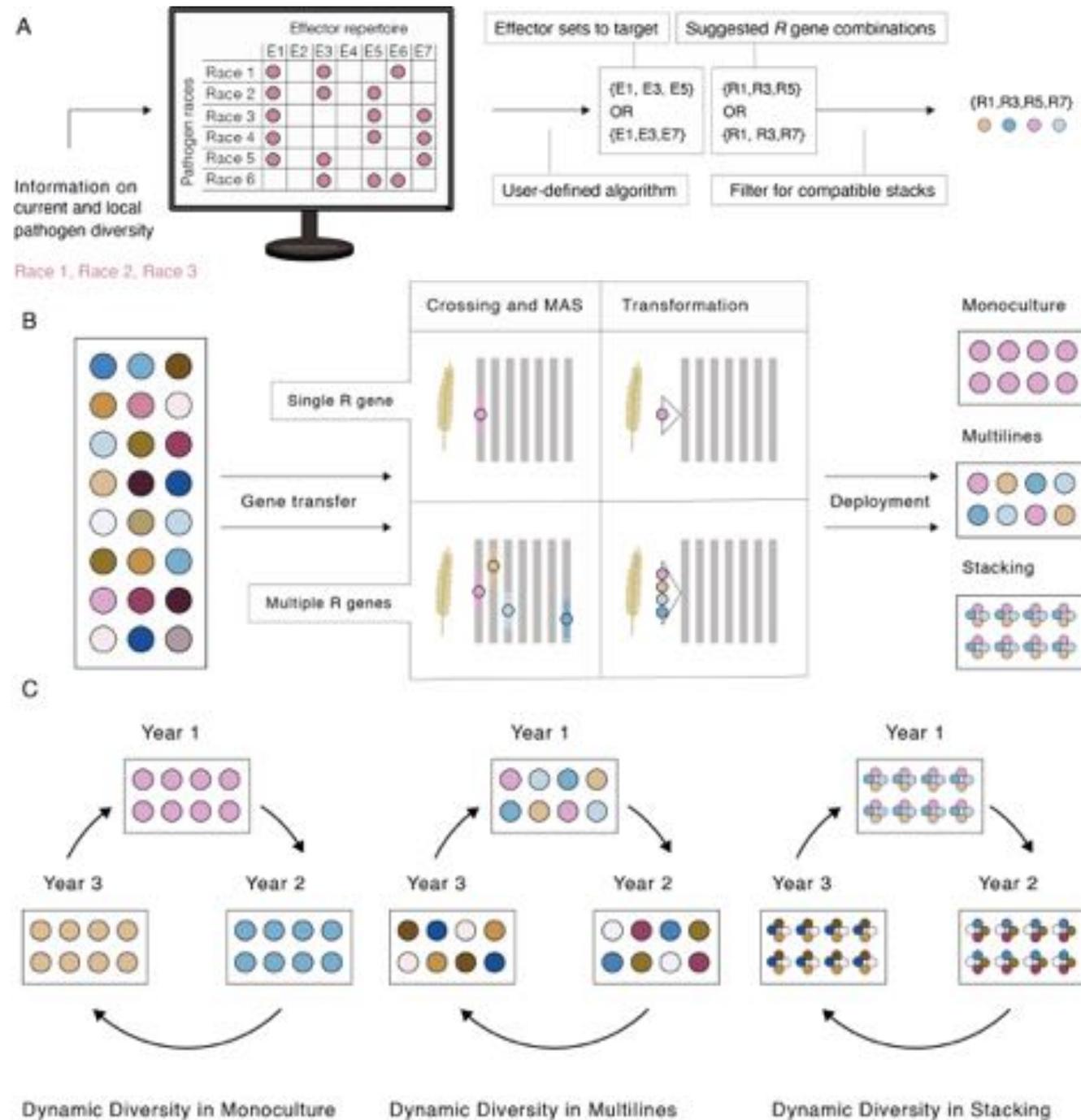


# R gene deployment

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# R gene deployment



Dynamic diversity:  
McDonald, 2014

# Gene stewardship

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# Gene stewardship

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Robert Bowden  
USDA



Viktor Korzun  
Nick Bird  
KWS



Wang Xiue  
Nanjing Agricultural University  
China



Ruth Wanyera  
KALRO



Brian Steffenson  
University of Minnesota



Sridhar Bhavani  
CIMMYT



Roger Freedman  
2Blades



Hannah Robinson  
Intergrain, Australia



Simon Berry  
Limagrain



Pierre Hucl  
University of Saskatchewan



Filippo Bassi  
ICARDA



Moisés Burachik



Franciso Ayala  
Bioceres, Argentina



Richard Summers  
Ruth Bryant  
RAGT Seed



Willem Boshoff  
Zakkie Pretorius  
University of the Free State, South Africa

# Gene stewardship

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*R* genes can be split into 3 groups:

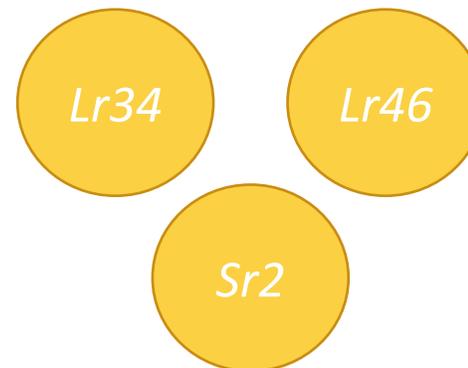
- **Group A**

- Inherently durable
- Do not require stewardship

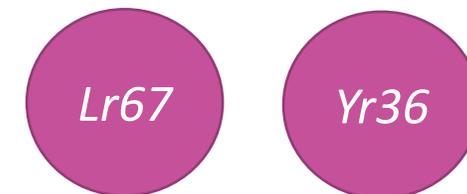
Widely defeated genes



Durable in the field



Non-race-specific immunity



Recessive, non-race-specific immunity

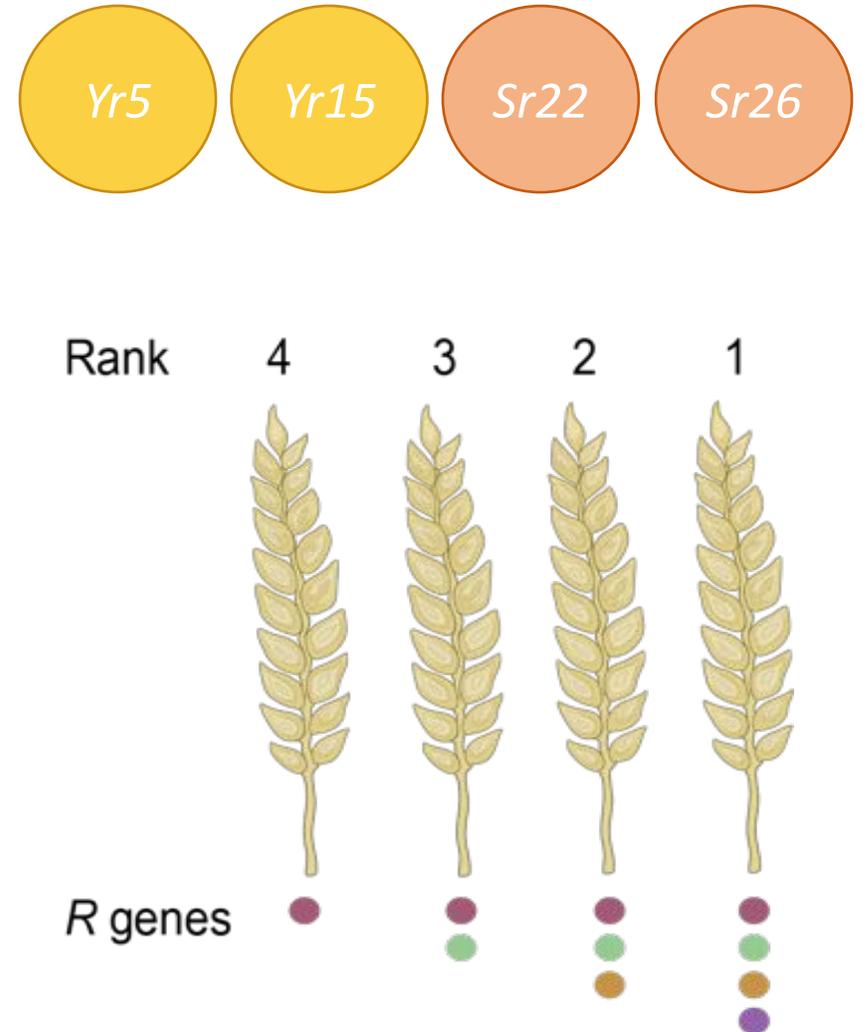


# Gene stewardship

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*R* genes can be split into 3 groups:

- Group A
- **Group B**
  - Vulnerable to defeat
  - Deploy only in stacks
  - Incentivise by awarding extra points to cultivars with durable resistance
  - Atlas can be used to design markers to assess *R* gene complement of existing varieties



# Gene stewardship

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*R* genes can be split into 3 groups:

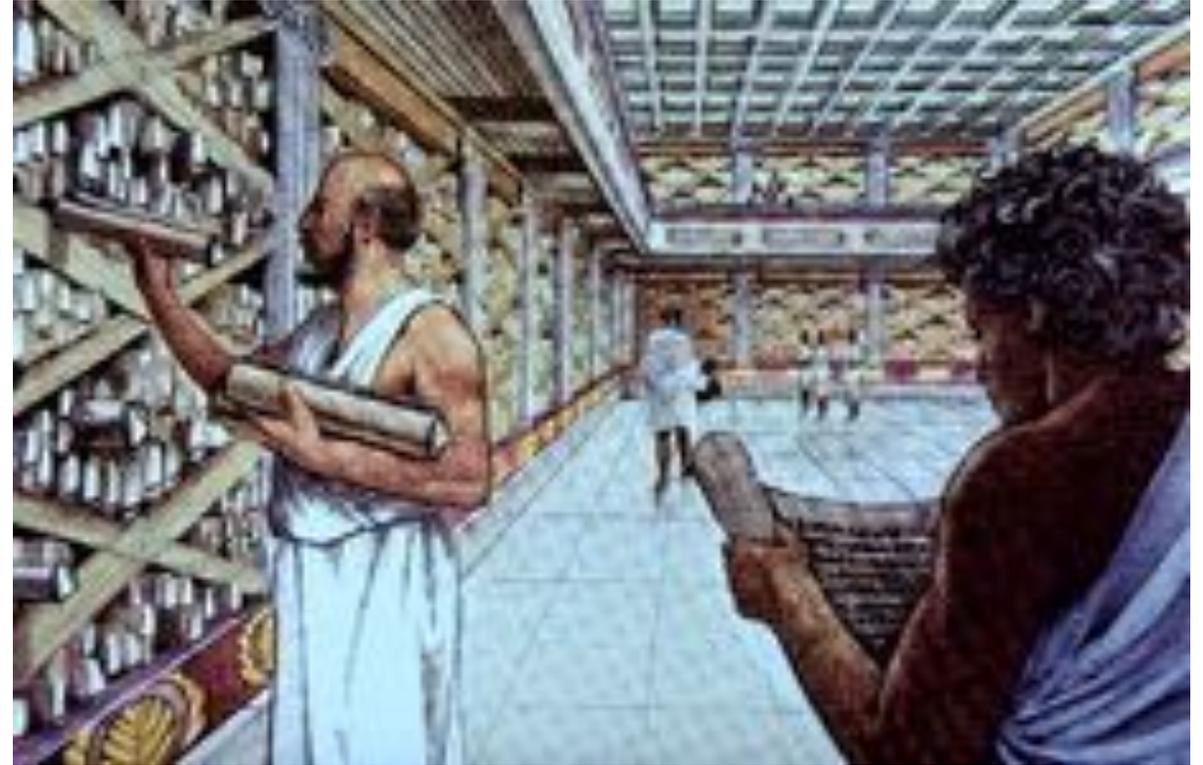
- Group A
- Group B
- **Group C**
  - Alien or synthetic *R* genes
  - Deployment could be managed through patenting





# Achieving the resistance gene machine

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# Thank you!



Brande Wulff



Sreya Ghosh



Sanu Arora



David Gilbert

John Innes Centre, Norwich



Robert Bowden  
USDA-ARS



Biotechnology and  
Biological Sciences  
Research Council



norwich research park

**Doctoral Training Partnership**

# 2BLADES

F O U N D A T I O N

**Figure design**

Tobin Florio

<https://floxbox-science.com/>

**Budget guidance**

Mark Luterbacher

**Taxonomic classifications**

Michiel van Slageren

**Patent searches**

Simon Aspland

Find our preprint on Zenodo: <https://zenodo.org/record/4469514#.YJJ4-6lKhps>